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Long-term Monitoring of bright Blazars with a dedicated Cherenkov Telescope

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We intend to set up an imaging air Cherenkov telescope with low cost, but high performance design for remote operation. The goal is to dedicate this γ-ray telescope to long-term monitoring observations of nearby, bright blazars at very high energies (VHE). We will (i) search for orbital modulation of the blazar emission due to supermassive black hole binaries, (ii) study the statistics of flares and their physical origin, and (iii) correlate the data with observations of flares with higher sensitivity telescopes such as MAGIC, VERITAS, and H.E.S.S. Common observations with the Whipple 10m monitoring telescope will be the first step towards a future 24h-monitoring of selected sources. This idea was presented for the first time in [1]. The telescope design is based on a full technological upgrade of one of the former telescopes of the HEGRA collaboration, still located at the Observatorio del Roque de los Muchachos on the Canarian Island of La Palma (Spain). After this upgrade, the telescope will be operated robotic, its sensitivity will greatly be improved and a much lower energy threshold below 350GeV will be achieved.

1. State-of-the-art

The current generation Cherenkov telescopes have impressively extended the physical scope of γ-ray observations. This became possible by lowering the energy threshold from 700GeV to less than 100GeV and increasing at the same time the sensitivity by a factor of five with respect to the former generation (see Fig. 3).

To fully exploit the discovery potential of these improvements, the discovery of new, faint objects has become the major task for the new telescopes. A diversity of astro-physical sources can be studied with them which limits their availability for monitoring purposes of well-known bright sources. There are, however, strong reasons to make an effort for the continuous monitoring of the few exceptionally bright blazars. This can be achieved by operating a dedicated robotic monitoring telescope of the HEGRA-type, referred to in the following as DWARF (**D**edicated multi**W**avelength **A**gn **R**esearch **F**acility).

3. Technical Setup

Telescope structure The former HEGRA telescope CT3, now owned by the MAGIC collaboration, will be refurbished and equipped for robotic operation to reduce costs and man power demands.

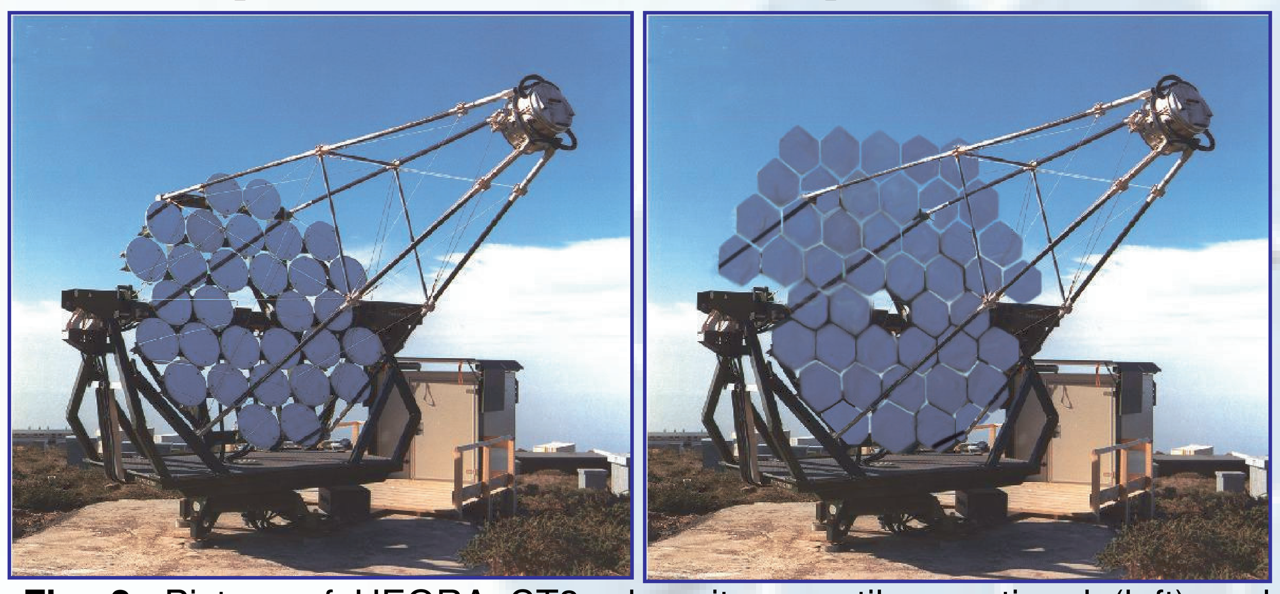

Fig. 2: Picture of HEGRA CT3 when it was stil operational (left) and photomontage of DWARF as it will look like after miror replacement (right).

Robotic operation For operating future networks of Cherenkov telescopes, e.g. a monitoring array around the globe or a single-place array like CTA or AGIS, it is mandatory to obtain know-how in their robotization. DWARF will be operated with only sparse human interaction which, in addition, will be done remotely via internet.

Drive system A microcontroller based motion control unit (SPS) like the one for MAGIC II and two 1.5kW servo-motors will be used.

Mirrors The existing mirrors are replaced by new plastic mirrors. The cheap and light-weight material will be copied from a master and coated with reflecting and protective material. By geometrical changes the mirror area is increased from 8.5m² to 13.5m² (see Fig. 2).

Data acquisition A hardware readout based on an analog sampling chip (Domino II/IV, developed at PSI [7]), currently designed for MAGIC II [8], will be used. By high sampling rates (≥2GHz), the over-all sensitivity will further be increased [9]. The automatic analysis package developed for MAGIC [10] can be used with minor changes for the DWARF project.

Performance The expected over-all performance is shown in Fig. 3.

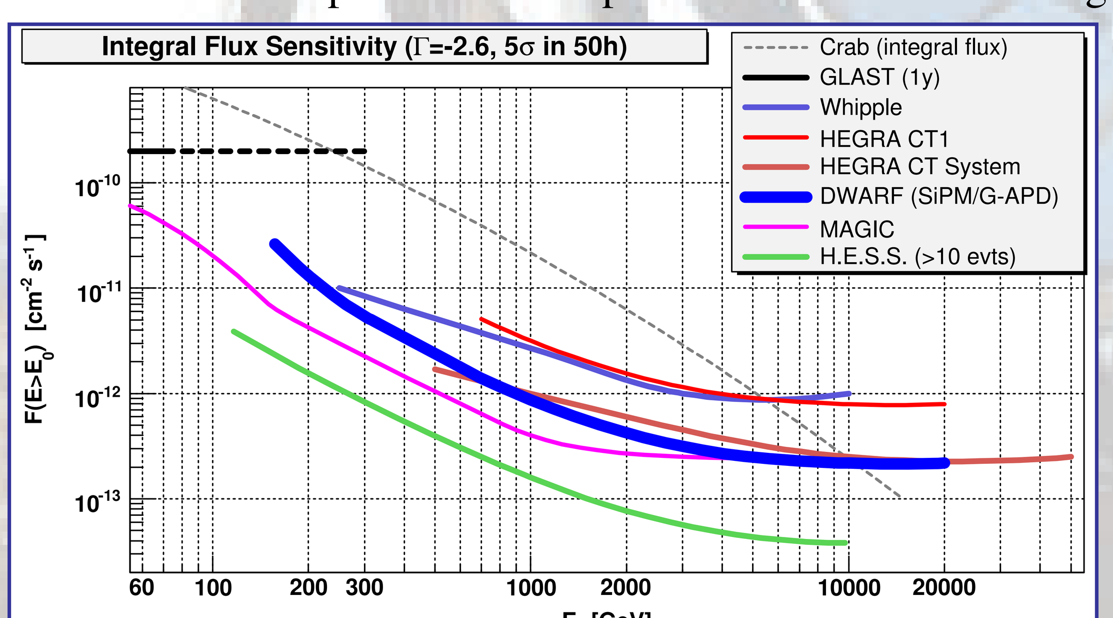

Fig. 3: Integral flux sensitivity of current and former Cherenkov telescopes as well as the expectations for DWARF, both with a PMT and a G-APD-camera [11,12,13].

2. Scientific motivation

The variability of blazars, seen across the entire electromagnetic spectrum, arises from the dynamics of relativistic jets and the underlying particle acceleration mechanisms. Recently, blazar VHE variability has been discovered on minute scales, but also variations on weekly or monthly scales are far from being understood.

To overcome the limitations of biased sampling, a complete monitoring database for variability investigations of a few representative bright sources needs to be built up.

DWARF will run as a facility dedicated to long-term monitoring of the following blazars only: Mrk421, Mrk501, 1ES 2344+514, 1ES 1959+650, H 1426+428, and PKS 2155-304. At least one of these targets will be visible any time of the year (see Fig. 1).

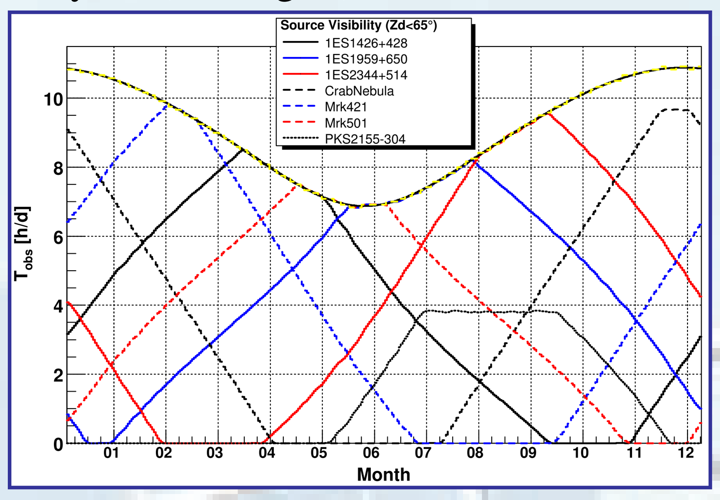

Fig. 1: Possible observation time per night for the given sources below 65° zenith angle.

Possible investigations:

- Determination of duty cycle, baseline emission, and power spectrum of flux variations.
- Interpretation of lightcurves using models for nonthermal emission from relativistically expanding plasma jets.
- Determination and comparison of the black hole mass and accretion rate from emission models, a possible orbital modulation and the Magorrian relation [2].
- Trigger MAGIC Target of Opportunity observations to obtain better time resolution for flaring states.
- Correlate neutrinos detected by IceCube with simultaneous measurements of DWARF to test the hypothesis of hadronic emission processes [3,4].
- Multi-frequency observations together with the Metsähovi Radio Observatory and the optical Tuorla Observatory as well as satellite experiments are planed.
- Search for signatures of binary black hole systems from orbital modulation of VHE γ-ray emission [5]. Possibly, computation of gravitational wave templates to establish their discovery with LISA.

Furthermore, operating a smaller but robotic telescope is an essential contribution to the next plans in ground-based gammma ray astronomy. For further details see [1,6].

4. First Avalanche-diode Camera Test

Recent tests have proven that Geiger-mode Avalanche Photo Diodes (G-APDs, also known as SiPMs or MPPCs) are a promising alternative to classical Photomultipliers for the detection of Cherenkov light from air showers [14,15].

This Camera will be the first Atmospheric Cherenkov Camera based on G-APD technology.

G-APD properties *(also see* [16])

- higher photo detection efficiency than PMTs (~60%)
- low operation voltage (<100V)
- very robust (no damage from accidental exposure to light)
- very reproducible output signal per photoelectron (see Fig. 4)
- acceptable timing properties

Baseline Design

- each G-APD is equipped with a special Winston Cone
- signal of 4 G-APDs („pixel“) added linearly and amplified
- flexible trigger logic

Camera construction in three stages

Stage 0: System test with 1 Module (144 G-APDs, 1° FoV)

Stage 1: 3° Camera for test on Crab Nebula

Stage 2: final design (5° FoV Camera)

Fig. 5 shows the photon distribution in the camera plane from a simulated γ-ray and proton shower in a Stage 1 or Stage 2 Camera. For further details see [17].

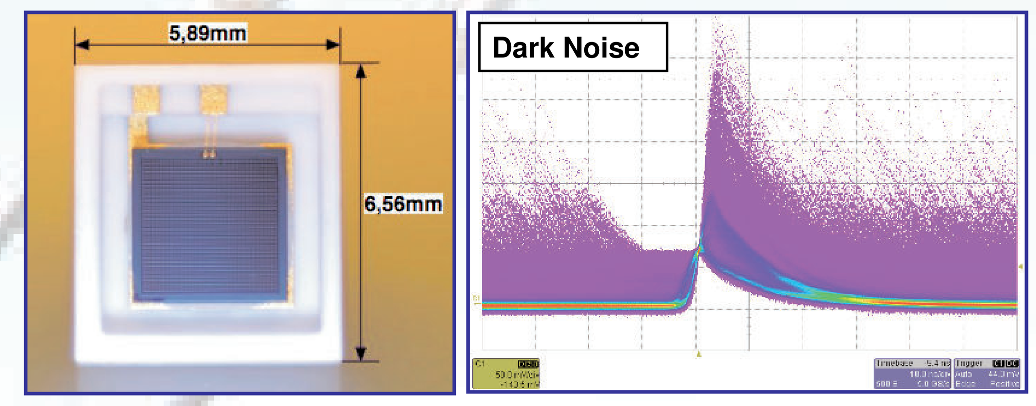

Fig. 4: The selected Hamamatsu MPPC S10362-33-100C (left) and its typical dark noise signal after amplification (right), horizontal scale: 10ns / div, vertical scale: 50mV / div

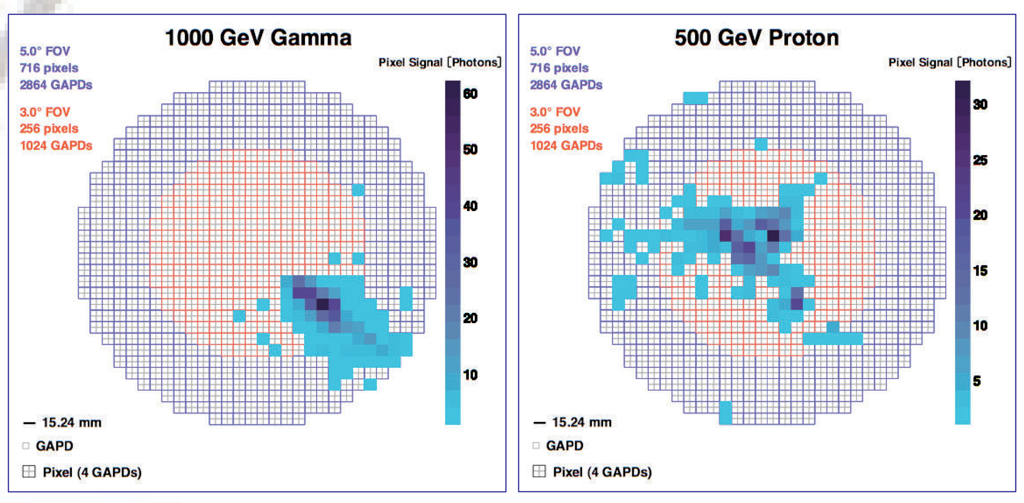

Fig. 5: Simulated photon distribution for a 1TeV γ-ray (left) and a 500GeV proton (right), the shaded areas correspond to a 3° (red) and 5° field of view (blue), 2x2 G-APDs (fine lines) form a pixel (stronger lines).

5. Future extensions

As of known duty cycle limitations of single place telescopes, we propose a worldwide network of (<10) small scale Cherenkov telescopes to be build in the future: A system so far unique in this energy range, which will allow 24h monitoring of bright AGN. The approved cooperation with the Whipple 10m-telescope is the first step in this direction (see Fig. 6).

Fig. 6: Possible distribution of Cherenkov telescopes in a future worldwide network for 24h AGN monitoring.

6. Conclusion

The setup of a small robotic telescope dedicated to long-term AGN monitoring is easily feasible. Such an activity is motivated by a variety of physical questions to be answered by the integration of this instrument in multiwavelength observations.

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